

EPIDOTE FROM HAWLEYVILLE, CONNECTICUT*

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ABSTRACT

The Hawleyville, Conn. epidote occurs in a prochlorite-apatite-orthoclase pegmatite along nearly horizontal fracture planes of a medium- to coarse-grained diorite. The occurrence is unusual since the epidote is colorless to yellow brown with a radiating prismatic habit. Optical and x-ray data are presented and the material is compared with the structurally and chemically similar zoisite and clinozoisite. The distinguishing features of the members of the epidote group are reviewed. It is suggested that the mineral name "epidote" be restricted to material which is optically negative. Indices of refraction are presented for stilbite which appear to represent a high Ca variety.

INTRODUCTION

This locality was first brought to the writer's attention in an article by Wm. Agar and Earl H. Emendorfer on the manganiferous prochlorite at Hawleyville, Conn. (Agar and Emendorfer, 1937). After visiting the locality in connection with research on the chlorite minerals, a colorless to yellow brown radiating mineral was found closely associated with the prochlorite. Upon investigation, this mineral has been identified as epidote, although it lacks the characteristic pistachio green color normally associated with epidote.

I express my sincere appreciation to Professors Paul F. Kerr and Ralph J. Holmes of Columbia University for their helpful criticism of this paper.

LOCATION

Hawleyville, Conn., is east of Danbury, Conn., on route 25 a few miles north of the junction of routes 6 and 25 (Fig. 1). The samples were taken from an east-west trending railroad cut one third of a mile west of Hawleyville near the northwest border of the township of Newton, Conn. The railroad cut may be reached by taking the dirt road marked Sky Ridge which runs in a westerly direction from route 25 south of Hawleyville. The Sky Ridge road is shown as a dotted line in Fig. 1.

GEOLOGY

The Brookfield Diorite

The prominent outcrop through which the New York and New England Railroad (a branch track also used by the New York, New Haven and Hartford R.R.) has made a deep cut along Sky Ridge near Hawley-

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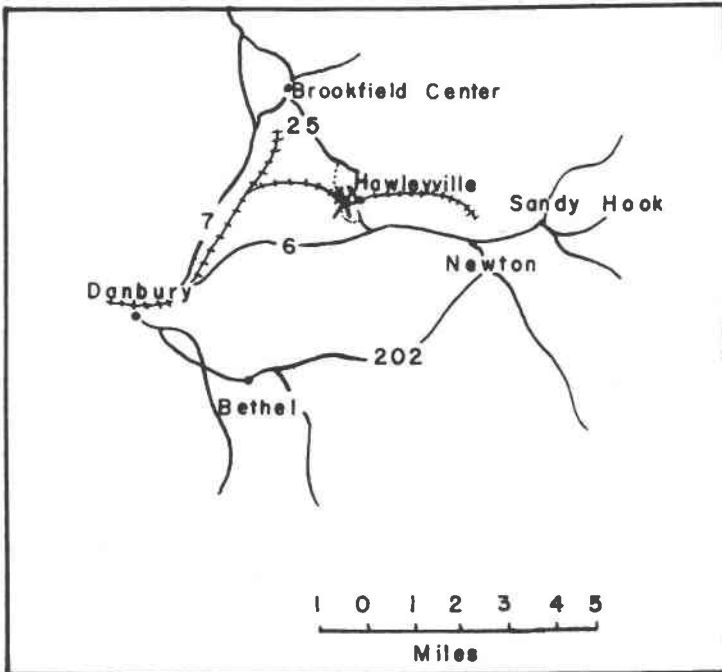
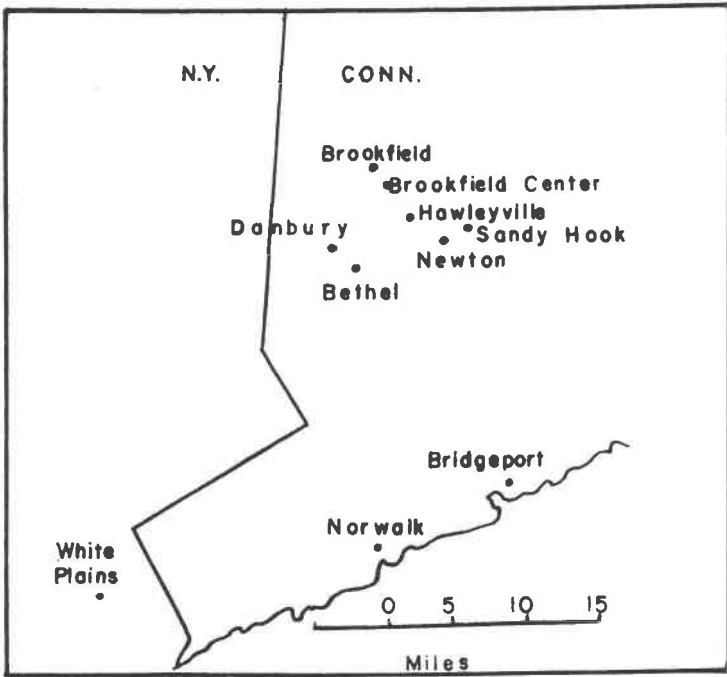


FIG. 1. Location of Hawleyville epidote.

ville is composed of medium- to coarse-grained diorite. Megascopically it is even textured and composed of equant grains of plagioclase, white orthoclase, and biotite. The white orthoclase grades into pink orthoclase near the epidote-chlorite veins to be described later. In thin section it may be seen that this pink color is the result of clouding by small flakes of hematite.

A thin section study of the Brookfield diorite revealed the following approximate composition:

25% to 30% biotite
 25% microcline
 25% plagioclase
 5% Ab_9An_1
 15% Ab_8An_2
 5% Ab_7An_3
 17% orthoclase
 8% to 13% quartz, ilmenite, zircon, and apatite.

The quartz does not exceed 5%. The ratio of alkali feldspar to plagioclase is about 5:3 and the ratio of microcline to orthoclase is about 3:2. The absence of hornblende is very striking both in hand specimen and thin section, emphasizing the similarity between the Brookfield diorite and a typical monzonite.

There are at least three prominent fracture systems which have been important in localizing various types of pegmatites. Although their occurrences are somewhat irregular, there is a dominant system which dips approximately 15 degrees to the west and strikes northwest. Another conspicuous series of fractures dips about 15 degrees to the east and strikes southeast. A third nearly vertical system strikes north-south, transecting the two nearly horizontal sets of fractures. It is these three systems which appear to have localized the later pegmatitic intrusions (Fig. 2).

On the south wall of the cut about 200 feet from the overpass and four feet above the railroad tracks, there is a narrow band of schistose rock which has a bulk composition similar to the composition of the Brookfield diorite. This band, four to six inches wide, parallels the dominant westward dipping fracture system, but pinches out into normal diorite eastward at its upper end (Fig. 2). The mica in the schistose band appears to be a light brown phlogopite or muscovite. The loosely layered character of this band has made it more susceptible to both replacement and weathering.

The Pegmatites

Although there are three distinct types of pegmatites intrusive into the diorite, two of these contain only feldspar crystals and massive quartz

with muscovite crystals along the pegmatite border. The third type is a complex feldspar-quartz pegmatite paralleling the two nearly horizontal fracture systems.

The pink feldspar-epidote-chlorite bearing solutions evidently followed vertical fractures until they intersected the westward dipping schistose band. This band then offered an easy path for the solutions so that they replaced the band laterally and down the dip. In addition to this schistose

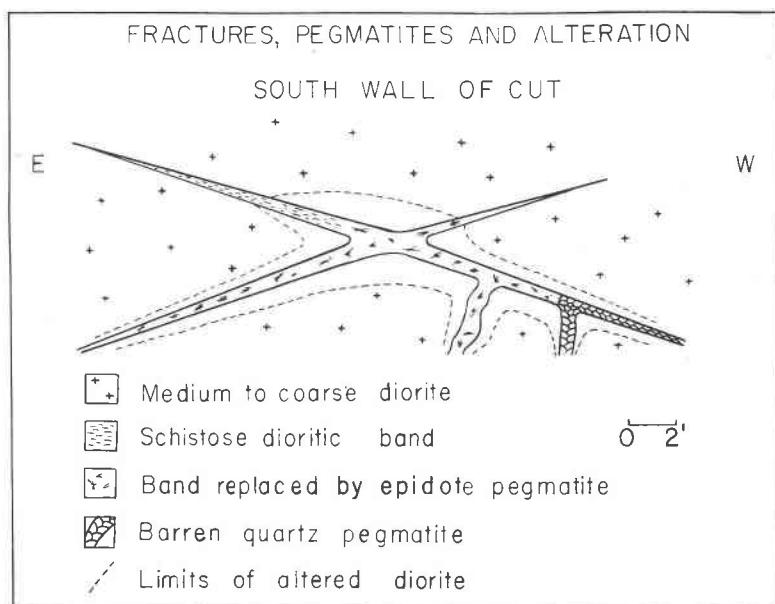


FIG. 2

band, the normal diorite has been altered in the immediate vicinity of the pegmatite. This alteration consists primarily of hematite-clouded pink orthoclase feldspar with minor amounts of plagioclase and biotite and forms a gradational transition zone between the pink orthoclase crystals bordering the pegmatite and the normal diorite. The extent of this replacement halo does not exceed two feet beyond the epidote-chlorite pegmatite center.

A few feet to the east there is another feldspar-epidote-chlorite pegmatite following an eastward dipping fracture system so that these two oppositely dipping pegmatites intersect about five feet above the base of the rock cut. There is no visible feeder for this second pegmatite (Fig. 2).

Geologic Sequence

The following is a probable recapitulation of the sequence of events:

1. Intrusion of a diorite body which cooled rather slowly yielding a medium to coarse texture.
2. Fracturing and some slippage creating faults and a weak zone of schistose structure; —not necessarily contemporaneously.
3. Influx of feldspar-epidote-chlorite solutions following vertical fractures but crystallizing preferably along the nearly horizontal fracture systems with notable replacement of the orthoclase and microcline by clouded pink orthoclase.
4. Intrusion of nearly barren quartz pegmatites in one or more stages.
5. Deposition of stilbite along vertical fractures.

MINERALOGY

The Pegmatites

The center of the feldspar-epidote-chlorite pegmatites contains straw yellow to nearly colorless radiating crystals of epidote, yellow to colorless crystals of apatite, and a few elongated milky quartz crystals in a matrix of deep green, nearly cryptocrystalline prochlorite. According to Agar and Emendorfer (1937) the prochlorite contains a small amount of manganese.

The borders of these pegmatites usually consist of brown to greenish muscovite crystals, often in very compact books. They form along the margin of the pegmatite between the epidote-chlorite center and the pink orthoclase alteration rim. The pink orthoclase crystals are untwinned both megascopically and microscopically.

As a final phase of the mineralization, unrelated to the diorite intrusive and subsequent pegmatite formation, thin coatings of radiating white stilbite crystals formed along many of the vertical fractures.

The indices of refraction usually given for stilbite (Larsen and Berman, 1934) are $\alpha=1.494$, $\beta=1.498$, and $\gamma=1.500$. However, the indices determined for the Hawleyville material are $\alpha=1.485 \pm .002$, $\beta=1.490 \pm .002$, and $\gamma=1.493 \pm .002$.* The index liquids used were checked on an Abbe refractometer using a sodium light source. All the other optical properties coincide with the optical properties for stilbite (Larsen and Berman, 1934). As supporting identification, an x-ray powder photograph was made with a Debye-Scherrer camera using filtered Cu radiation. The pattern of the Hawleyville stilbite matches the values given in the *A.S.T.M.* Index for stilbite from Palm Grove, Victoria Falls, Zambesi River, N. Rhodesia and it also matches the pattern of stilbite from Poonach, India, in the mineralogy laboratory reference files at Columbia University. Consequently the Hawleyville material may be iden-

* Similar to the low indices of the high Ca-variety, stellarite; Neuman, *Norges Geol. Undersokelse*, No. 166, 108-113 (1944); Pabst, *Min. Mag.*, 25, 271 (1939).

tified as stilbite. From this data it seems probable that stilbite may have a range of indices of refraction greater than previously reported.

The Hawleyville Epidote

Ordinarily epidote is pistachio green and occurs in single crystals or parallel groups. This epidote, however, varies from nearly colorless to straw yellow to light green and commonly forms large radiating groups of crystals. Such a deviation marks this as an unusual occurrence and worth investigation. A colorless epidote from Garda in northern Italy may be a similar variety (Lacroix, 1887). No specimen was available for comparison.

Although on first glance these crystals resemble vesuvianite, the two minerals most likely to be confused with this epidote are zoisite and clinozoisite. Indeed all belong to the same family, which also includes piedmontite, withamite, allanite, manganepidote, thulite, and hancockite. Of these only epidote, allanite, manganepidote, withamite, and hancockite are optically negative. Thus a distinction between epidote on the one hand and zoisite and clinozoisite on the other rests on the difference in optic sign.

In its own optic group epidote may be distinguished from withamite by an absence of strong red pleochroism and a negligible manganese content; from hancockite by lower indices of refraction; from manganepidote by lower birefringence, lower indices of refraction, and the absence of significant amounts of manganese, and from allanite by lower birefringence, an absence of rare earth elements, its greenish color, and by its lack of radioactivity.

The properties of the Hawleyville epidote are as follows:

Color: colorless, straw yellow, brownish yellow, and yellowish green.

Habit: radiating prismatic with occasional bent crystals.

Specific gravity: $3.321 \pm .006$.

Refractive indices: $\alpha = 1.726$.

$\beta = 1.735$.

$\gamma = 1.741$.

Optic sign: negative.

Pleochroism: X—colorless.

Y—occasionally faint pale pink.

Z—colorless to neutral.

Interference colors: regular, not anomalous.

Twinning: rarely polysynthetic on (100) 2V greater than 50°.

The pistachio green color of epidote is usually considered to be due to its high iron content while the lighter color of clinozoisite is believed to be the result of less than ten per cent iron. Zoisite, which is usually still lighter in color, contains little or no iron (Dana-Ford, 1932). In addition, the optic sign changes from positive to negative, distinguishing clino-

zoisite from epidote in this iron replacement series. Both the indices of refraction and birefringence increase with increasing iron content. A comparison of iron content with color and indices of refraction for minerals of this group from several localities is shown in Table 1. The Hawleyville, Conn., material is included based on an analysis by W. H.

TABLE 1. RELATION OF IRON CONTENT TO COLOR AND INDICES OF REFRACTION

| $\%Fe_2O_3$ | $\%FeO$ | $\%Fe$ | Color | Indices | Biref. | Ref. |
|-------------|---------|--------|--------------------------|-------------------------|--------|------|
| 3.52 | .35 | 2.73 | golden green | 1.724 1.729 1.734 | .010 | 10. |
| 7.62 | | 5.33 | green | 1.706 1.708 1.712 | .006 | 8. |
| | 7.83 | 6.08 | colorless | | | 11. |
| 9.67 | | 6.77 | olive green | 1.722 1.742 1.750 | .028 | 4. |
| 8.88 | .97 | 6.97 | straw yell.-green | 1.726 1.735 1.741 | .015 | 1. |
| | | 12.0 | colorless or green* | 1.716 1.719 1.723 | .007 | 7. |
| | | 13.0 | dark green to gray brown | 1.714 1.719 1.725 | .011 | 9. |
| 15.53 | | 10.85 | pistachio green | | | 5. |
| 17.25 | | 12.06 | pistachio green | 1.729 1.763 1.779 | .050 | 4. |
| | | 22.0 | pistachio green | 1.722 1.742 1.750 | .028 | 7. |
| | | 23.0 | dark green | | .033 | 2. |

* Both colors are given by Larsen and Berman (1934) in different tables apparently for the same mineral.

Note: $\%Fe$ was calculated from given oxide per cent.

Herdsmen given below in Table 2. It can be seen from the standpoint of color alone, the Hawleyville epidote would probably have less than 15% iron. That it might have less than the 10% stipulated as the boundary per cent between clinozoisite and epidote (Dana-Ford, 1932) may be seen by the colorless Garda epidote with a 7.83% FeO content. As regards the indices of refraction, the high α index of the Hawleyville epidote suggests a relatively high iron content, while the low birefringence (.015) suggests

TABLE 2

| Oxide | % |
|--------------------------------|-------|
| SiO ₂ | 37.96 |
| Al ₂ O ₃ | 27.34 |
| FeO | .97 |
| Fe ₂ O ₃ | 8.88 |
| MnO | .16 |
| CaO | 22.07 |
| MgO | .34 |
| H ₂ O-105° | .08 |
| H ₂ O+105° | 2.14 |
| | 99.94 |

Analysis by W. H. Herdsmen, Glasgow, Scotland.

a moderate iron content. The chemical analysis given in Table 2 confirms these conclusions regarding iron content based on the color and optical properties of the epidote. It should be noted that both total iron per cent and total iron oxide per cent are less than the stipulated 10% often regarded as the minimum iron content for epidote. On the other hand, if one were to define epidote on the basis of a negative optic sign, the Hawleyville material would have to be regarded as epidote and not as clinozoisite.

It is interesting to note that, as might be expected from the associated manganese-bearing chlorite, the epidote also contains a small percentage of manganese. Evidently this quantity is insufficient to affect the optical properties appreciably. It is certainly insufficient for this mineral to be regarded as one of the manganese epidote minerals mentioned previously.

In an effort to distinguish the Hawleyville epidote from the structurally similar clinozoisite and zoisite, several x -ray powder photographs were taken. A Debye-Scherrer camera was used with Cu radiation and a Ni filter. Each pattern was measured independently several times to decrease the margin of error of two-theta measurement. The intensities shown in Table 3 are the averages of at least three independent visual estimates for each powder pattern.

The zoisite from Ducktown, Tenn., is greenish and optically positive. The Bourg d'Oisans epidote from France, is pistachio green, contains 14.88% iron, and is optically negative. The "clinozoisite" from Nightingale Range, Nev., is gray, but optically negative, and therefore probably an epidote. The clinozoisite from Timmins, Ont. (Fouqueite) is gray-brown, radiating prismatic, and optically positive. This Timmins clinozoisite is here taken to be representative of clinozoisites as a whole. Although it can be seen from Table 3 that these are all similar minerals, the following distinctions may be made:

1. The Hawleyville epidote exhibits a 7.02 Å and a 1.590 Å line, neither of which are present in the Timmins clinozoisite.
2. The Timmins clinozoisite has 6.60 Å, 3.325 Å, and 2.631 Å lines not found in any of the epidote patterns.
3. There do not seem to be any significant intensity variations between the epidotes and the clinozoisite, but the zoisite is significantly different.
4. The 3.325 Å and 2.631 Å lines of the Timmins clinozoisite are common to the zoisite, but are not found in the three epidotes.
5. The Nevada "clinozoisite" (actually epidote) and the Hawleyville epidote have consistently greater "*d*" spacing values for the same reflections than the Timmins clinozoisite and the Bourg d'Oisans epidote. The former pair correspond to lighter colored hand specimens and the latter to darker hand specimens, suggesting that the coloring agent or agents is shifting the "*d*" reflections to smaller values. In the light of the optical properties and chemical analysis, it seems probable that iron content is the major factor involved in this shift.

CONCLUSIONS

There is no prominent structural difference among the five samples which were examined by *x*-rays. However, the zoisite "*d*" value shifts, as well as the significant intensity variations indicate that there is some structural dissimilarity. Ito (1947) has proposed that zoisite is twinned clinozoisite. Such intimate twinning resulting from a change in position of Al(Fe) octahedra with respect to Al tetrahedra might explain the differences observed in the powder patterns of these two minerals. In addition, as the composition changes from the light gray zoisite to the dark pistachio green of the Bourg d'Oisans epidote, the 6 Å, 7 Å, and 8 Å lines gradually disappear, the 8 Å line being the last to disappear. This represents a structural change which may be a reflection of increasing iron content.

If the Timmins clinozoisite is accepted as a typical clinozoisite, then a consideration of the *x*-ray data leads to the conclusion that the structural similarity between epidote and clinozoisite is greater than the similarity between either epidote and zoisite or clinozoisite and zoisite. This is in sharp contrast to the optical properties. Optically, clinozoisite and zoisite are similar, both being positive, while epidote is optically negative. Since the optical properties of a mineral are also a direct consequence of its

TABLE 3. COMPARISON OF X-RAY VALUES FOR MEMBERS OF THE EPIDOTE GROUP

| Zoisite Ducktown, Tenn. | | Epidote Bourg d'Oisans | | "Clinozoisite" Nightingale R. Nev. | | Epidote Hawleyville | | Clinozoisite Timmins, Ont. | |
|-------------------------------|-------|------------------------------|-------|--|-------|------------------------|--------------|----------------------------------|---------------|
| Int. | d(Å) | Int. | d(Å) | Int. | d(Å) | Int. | d(Å) | Int. | d(Å) |
| 30 | 8.13 | | | 3 | 8.08 | 4 3 | 7.98 7.02 | 8 | 7.93 |
| 50 | 5.027 | 40 | 4.950 | 50 | 5.038 | 40 | 5.018 | 6 35 | 6.60 4.992 |
| 15 | 4.675 | $\frac{1}{2}?$ | 4.543 | $\frac{1}{2}?$ | 4.631 | $\frac{1}{2}?$ | 4.621 | | |
| 8 | 4.245 | | | | | | | | |
| 40 | 4.048 | 50 | 3.969 | 50 | 4.006 | 40 | 3.997 | 45 | 3.997 |
| | | 1 | 3.732 | 2 | 3.749 | $\frac{1}{2}?$ | 3.762 | 3 | 3.751 |
| 60 | 3.615 | 45 | 3.450 | 45 | 3.487 | 40 | 3.492 | 30 | 3.468 |
| | | 20 | 3.370 | 3 | 3.394 | 6 | 3.372 | 8 | 3.390 |
| 2 | 3.328 | | | | | | | 6 | 3.325 |
| | | 30 | 3.176 | 12 | 3.207 | 15 | 3.197 | 20 | 3.184 |
| 35 | 3.106 | | | $\frac{1}{2}?$ | 3.060 | $\frac{1}{2}?$ | 3.060 | 2 | 3.044 |
| 100 | 2.869 | 100 | 2.872 | 100 | 2.893 | 100 | 2.900 | 100 | 2.884 |
| 35 | 2.783 | 60 | 2.795 | 65 | 2.805 | 50 | 2.809 | 55 | 2.790 |
| 100 | 2.703 | | | | | | | | |
| 20 | 2.626 | 70 | 2.667 | 65 | 2.676 | 60 | 2.677 | 60 | 2.666 |
| | | | | | | | | 12 | 2.631 |
| 30 | 2.531 | 65 | 2.588 | 60 | 2.593 | 55 | 2.593 | 60 | 2.584 |
| $\frac{1}{2}?$ | 2.459 | 30 | 2.514 | 15 | 2.529 | 10 | 2.525 | 15 | 2.511 |
| 40 | 2.407 | 10 | 2.439 | 2 | 2.449 | 6 | 2.449 | 12 | 2.437 |
| 60 | 2.335 | 80 | 2.393 | 75 | 2.397 | 70 | 2.396 | 65 | 2.385 |
| 10 | 2.238 | 45 | 2.290 | 25 | 2.296 | 25 | 2.289 | 25 | 2.285 |
| | | | | | | | | | |
| 10 | 2.111 | 50 | 2.152 | 25 | 2.162 | 25 | 2.161 | 25 | 2.153 |
| 65 | 2.064 | 60 | 2.103 | 40 | 2.110 | 40 | 2.111 | 35 | 2.099 |
| | | 20 | 2.064 | 3 | 2.067 | 10 | 2.065 | 6 | 2.060 |
| 5 | 2.020 | 5 | 2.038 | $\frac{1}{2}?$ | 2.044 | $\frac{1}{2}?$ | 2.043 | $\frac{1}{2}?$ | 2.043 |
| 15 | 1.982 | | | | | 1 | 2.020 | | |
| 20 | 1.903 | | | $\frac{1}{2}?$ | 1.997 | 1 | 2.003 | $\frac{1}{2}?$ | 1.994 |
| | | 2 | 1.915 | | | $\frac{1}{2}?$ | 1.914 | | |
| 30 | 1.844 | 70 | 1.867 | 70 | 1.871 | 60 | 1.869 | 60 | 1.865 |
| | | | | | | | | | |
| | | 1 | 1.767 | | | 1 | 1.773 | 1 | 1.765 |
| $\frac{1}{2}?$ | 1.715 | $\frac{1}{2}?$ | 1.741 | | | 1 | 1.742 | $\frac{1}{2}?$ | 1.740 |
| 8 | 1.685 | $\frac{1}{2}?$ | 1.700 | | | 1 | 1.705 | $\frac{1}{2}?$ | 1.699 |
| 4 | 1.666 | $\frac{1}{2}?$ | 1.682 | | | 1 | 1.687 | $\frac{1}{2}?$ | 1.684 |
| | | $\frac{1}{2}?$ | 1.666 | | | 1 | 1.669 | | |
| | | 85 | 1.635 | 75 | 1.633 | 65 | 1.635 | 65 | 1.631 |
| 75 | 1.615 | 20 | 1.622 | 12 | 1.622 | 10 | 1.622 | 20 | 1.618 |
| 25 | 1.591 | | | 20 | 1.585 | 10 | 1.590 | | |
| | | 25 | 1.575 | 20 | 1.575 | 12 | 1.574 | 15 | 1.571 |
| 20 | 1.544 | 20 | 1.541 | 6 | 1.539 | 6 | 1.539 | 6 | 1.536 |
| | | | | 2 | 1.530 | | | $\frac{1}{2}?$ | 1.524 |
| 35 | 1.453 | 40 | 1.456 | 20 | 1.457 | 15 | 1.458 | 25 | 1.451 |
| 10 | 1.429 | 2 | 1.437 | 4 | 1.435 | 6 | 1.435 | 6 | 1.433 |
| $\frac{1}{2}?$ | 1.406 | 55 | 1.406 | 30 | 1.404 | 30 | 1.404 | 35 | 1.398 |
| 45 | 1.388 | 50 | 1.392 | 15 | 1.393 | 25 | 1.389 | 15 | 1.388 |
| 2 | 1.369 | 1 | 1.363 | | | | | | |
| 30 | 1.347 | 8 | 1.344 | 2 | 1.342 | 4 | 1.346 | 1 | 1.339 |
| 20 | 1.291 | 8 | 1.295 | 4 | 1.296 | 6 | 1.297 | 4 | 1.2934 |
| 8 | 1.268 | 12 | 1.267 | 20 | 1.265 | 8 | 1.265 | 10 | 1.262 |

structural arrangement, this seems to present a paradox. Epidote has been regarded as an iron-rich zoisite and presumably the change in optic sign could be attributed to the increase in iron content. A similar feature occurs in the forsterite-fayalite series in which there is a continuous transition from the optically negative iron-rich member, fayalite, to the optically positive forsterite. Olivine of intermediate composition, may be either positive or negative.

Tempel (1938) found that the presence of rare earths, in addition to the water and ferrous-ferric content, influences both the physical and optical properties of epidote. Thus even a chemical classification becomes a complex problem. Since ferric iron is able to substitute diadochically for aluminum in the epidote structure, it seems that the distinction between epidote and clinozoisite, at least for the present, should be based on the difference in optic sign which reflects both the chemical and the slight structural dissimilarities of the two minerals.

The Hawleyville material may be considered to be an epidote as long as the definition of epidote rests upon the optic sign determination. However, should clinozoisite eventually take the analogous position of olivine as either optically positive or negative, then the Hawleyville material will have to be reclassified on another basis. Additional *x*-ray analyses on the effect and position of iron substitution in the members of the epidote group might reveal a better basis for differentiating the minerals of this group.

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